Soil carbon sequestration in land use types of an oil palm based cropping system

Comment [I1]: Title is not justified as all LUT are not based on or having Oil Palm

Abstract

Assessing the influence of agricultural land use on soil carbon sequestration is important for the managing of soil carbon stocks in cultivated sandy soils. Soil carbon sequestration in different land use types was studied in Benin, Edo State, and Nigeria. Three oil palm fields, OM1, OM2, and OM3, of different years of establishment and management practices were selected, along with nursery (NUR), livestock (LIV), vegetable (VEG), arable (ARB), and fallow (FAL) land. Soil samples were collected in the representative portion of each land use and analyzed for particle size distribution, bulk density, total nitrogen, available phosphorus, organic carbon, and pH, while the soil carbon sequestration was calculated. OM1 (6.72 tons/ha) and LIV (6.40 ton/ha) sequestered more carbon than other land uses, revealing the potential of oil palm to sequester carbon in sandy soils. There is a relationship between bulk density and soil carbon sequestered in the land use; therefore, practices that will improve the soil bulk density and increase the soil organic matter were recommended.

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Keywords: land, oil palm, carbon, sequestration, sand

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1. Introduction

A prominent challenge in the current era is the issue of global warming, which is primarily attributed to the presence of greenhouse gases like carbon dioxide (CO_2), methane (CH4), and nitrous oxide (N_2O). By reflecting the earth's long-wave radiation, greenhouse gases trap heat on the planet. There was an increase in carbon dioxide levels from around 280 ppm in pre-industrial times to 379 ppm in 2005, methane levels from 715 to 1732 ppb, and nitrous oxide levels from 270 to 319 ppb [1]. Increased fossil fuel consumption, land use changes, and vegetation deterioration to support a growing population have resulted in the release of large amounts of greenhouse gases into the atmosphere [2], resulting in air pollution, temperature increases, and climate change in general.

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Soils store a significant amount of carbon. It has been estimated that global soils contain approximately 1.5 x 10^{12} metric tons of carbon [3]. As a carbon cycle component, soils can be either net sources or net sinks of atmospheric carbon dioxide. Changes in land use and agricultural activities during the past 200 years have made soils act as net sources of atmospheric CO_2 [4]. Long-term experiments suggests that carbon losses due to oxidation and erosion can be reversed with soil management practices that minimize soil disturbance and optimize plant yield through fertilization [5]. Improved land management has the potential to significantly increase the rate at which carbon is deposited in the soil because of the relatively long turnover times of some soil carbon fractions, this could result in storing a sizable amount of carbon in the soil for several decades [4].

Addressing the concentrations of carbon dioxide (CO2) and other greenhouse gases in the Earth's atmosphere is a key strategy in mitigating climate change [1]. The approach involves promoting carbon storage in the soil by sequestering atmospheric carbon as soil organic carbon (SOC).

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Soil carbon sequestration is a procedure for absorbing extra CO_2 from the atmosphere [6, 7]. This is to prevent carbon emissions produced by human activities from reaching the atmosphere by capturing and diverting them to secure storage and removing carbon from the atmosphere by various means and storing it [4].

SOC is a heterogeneous mixture of simple and complex organic carbon compounds that can be divided into different pools that serve different functions in soil ecosystems [8]. Soil quality is important for soil health and fertility, and thus for sustainable agriculture [8, 9].Soil carbon affects wide range of soil physical, chemical, and biological properties. It affects: soil aggregation, erosion, drainage, aeration, water-holding capacity, bulk density, evaporation, permeability, cation exchange capacity, metal complexing, buffering capacity, supply and availability of N, P, and S, and micronutrients; adsorption of pesticides and other added chemicals; and the activities of bacteria, fungi, actinomycetes, earthworms, roots, and other microorganisms.

Comment [I11]: Sentence not seems to be relevant to paragraph

Estimations indicate that by 2050, the global food system will face the challenge of nourishing a population of 9 billion individuals, a significant portion of whom will possess considerable wealth and desire a diet of high value[10], this would lead to the cultivation of more land, land degradation, stress on the natural environment, and an increase in climate change if left unchecked. It is therefore important to conduct studies on soil carbon sequestration. Research on soil carbon sequestration is a crucial scientific field in that, apart from the removal and deduction of CO_2 in the atmosphere, an increase in the SOC will lead to an improvement in soil productivity [11–15].

Research into carbon sequestration in agricultural soils is thus both related to sustainable agriculture and climate change mitigation and would fit perfectly within the Global Change and Ecosystems track of the Sustainable Development program [13]. An understanding of the level of SOC and soil carbon sequestration at a location will guide for the formulation of recommended management practices (RMPs) based on the activities identified that deplete or increase soil carbon at the location. This study characterizes some soil properties in different land use types of sandy soil, evaluates the influence of land use on soil carbon sequestration, and examines the relationship between soil properties and soil carbon sequestration in the different land use types.

2. Materials and method

2.1 Description of the study area

Comment [I12]: Mention the year of study

The study was conducted at the Institute for Oil Palm Research, Benin-City Nigeria. The area is located at 6° 21'N and 5° 39' to 5°30'E. The total annual rainfall amount is between 2,000 mm and 3,000 mm. It experiences double rainfall cycles, with the highest precipitation amounts occurring in the months of July and September. It has a relative humidity between 75% and 85% and a mean annual temperature of 27.5°C. It is in the humid rain forest agro-ecological zone and has a sub-equatorial climate. The area's geology is the sedimentary formation of the South Sedimentary Basin [16].

2.2 Land use types and history

The major land use in the area is agriculture, and the land utilization types (LUT) involve oil palm, nursery, arable cropping, livestock, and vegetable production. Some parts are uncultivated and fallow. The oil palm fields are of three types based on the year of establishment: field 45 1963. (OM1), field 02 1961 (OM2) and field 13 1975 (OM3). The nurseries (NUR), livestock (LIV), and vegetable (VEG) fields had been in use for over 30 years. The arable land (ARB) had been under continuous cultivation of cassava, yam, maize, melon, and rice for over 20 years. The fallow (FAL) land is a previously cultivated land that has been kept under 6 years.

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2.3 Soil sampling, experimental design and treatments

The soil was sampled at a representative portion of all the LUT in the area. Samples were taken randomly from a depth of 0–30 cm. The five LUTs were the treatments. Four samples, which represent four replicates, were taken from each LUT. Soil auger and core sampler were used to collect the soil samples. The experimental design is randomized complete block design.

Soil was sampled at the representative portion of all the LUT in the area. Samples were taken randomly from a depth of 0-30 cm. Four samples which represents four replicates were collected in each LUT. Soil samples were collected with soil auger and core sampler.

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2.4 Laboratory analysis

The samples were dried and put through a 2-mm sieve. To determine the bulk density of the soil, undisturbed core samples were used by oven drying [17]. The organic carbon was determined using the potassium dichromate method [18].

To estimate the content of the carbon and its total mass (weight) in the soil rather than its percentage, the carbon content (g) in the soil unit (kg) was used, as shown in Equation 1.

$$OC_{(grC/kg\ soil)} = \%OC \times 10 \quad (1)$$

where OC is the amount of organic carbon in one gram of carbon per kg of soil and OC% represents the organic carbon percentage of the soil. Equation 2 [19] calculates the organic carbon per unit area based on the weight of organic carbon per soil weight unit (gr C/Kg soil), the soil bulk density, and the depth of the soil.

$$Sc = e \times Bd \times OC_{(grC/kg\ soil)} \quad (2)$$

where Sc indicates the amount of carbon in the soil in tons per hectare at a certain depth, and e is the soil depth (meters). OC represents the organic carbon mass for a gram of carbon per kilogram of soil, and BD denotes the soil bulk density for a gram per cubic centimeter.

Particle size analysis (percentage of clay, silt, and sand) was determined using the hydrometer method [20].

Soil pH was determined in water at a soil/water ratio of 1:1 using a digital pH meter [21].

Total nitrogen was determined using the macro-Kjeldahl method [22].

Available phosphorus was determined using the Bray-1 extraction method [23]. The phosphorus in the solution was determined colorimetrically by the modified single solution procedure using ascorbic acid [24].

2.5 Statistical analysis

A one-way analysis of variance (ANOVA) was carried out, and then the means were compared using the least significant difference test at a 5% significance level. The land use types were the treatments, and four sampling points in each LUT were the replicates. It was fitted into a randomized complete block design. The coefficient of variation (CV) was determined, and a correlation analysis was carried out to evaluate the relationship between parameters. The statistical analysis of the data was done with Statistix version 16 software.

3. Results and discussion

3.1 Soil characterization

The results of the soil properties studied are presented in Table 1. The proportions of clay in the soils ranged from 3.100 to 9.100%, silt was from 6.025 to 7.400% the soils ranged from 3.100 to 9.100%, silt was from 6.025 to 7.400%, and sand was from 84.75 to 90.00%. There was a significant difference in the particle size distribution between the land use types. This can be a result of the nature of the soils at the location and variations in the mode of formation, which are influenced primarily by the movement of materials. Land use has been reported not to have an influence on the particle size distribution of soils [25, 26]. Clay is the most variable, with a coefficient of variation (CV) value of 51.759%; similar observations in soils around the study location have been reported [27]. The texture of the soil is loamy sand. The sandy nature of the soil can be attributed to the nature of the parent material, and it is in agreement with reports for soils formed on similar parent material in Nigeria [28-30].The bulk density values ranged from 1.400 to 1.453 g/cm^3. The values are within the range of 1.3–1.7 g/cm^3 suggested for sandy soils [31]. It was however less than the critical level of 1.6 g/cm^3 at which the growth of roots of crops will be restricted [32].

No significant difference between the land uses, and the CV of 1.822 percent indicates low variation.

The pH values ranged from 4.600 to 6.425. There was a significant difference between the land use types, and CV values of 12.129 percent were recorded, indicating moderate variation between the land uses. Fallow (FAL) and nursery (NUR) sites are very acidic; arable is moderately acidic,

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while the other land use types are strongly acidic. A pH range of 5.5–6.5 for most crops has been suggested [33, 34], which is within the range of strongly acidic to moderately acidic. This implied that only the soil of the vegetable gardens and arable land could support most crops and yield good crops. The acidic nature could be as a result of the sandy nature of the soils, which could have occasioned the loss of organic matter and leaching as well as the forest cover created by the oil palm plantation.

Available P values ranged from 4.705 to 26.060 mgkg1. There was a significant difference between the land use types. The CV of 107.72 percent was recorded, implying that available phosphorus is highly variable between land use types. Variation in soil chemical properties has been attributed to cultivation, contrasting crops, soil amelioration, and the addition of fertilizers [35]. The values recorded at the arable (ARB), oil palm field 3 (OM3), and vegetable garden (VEG) were below the critical value of 8.5 mg kg1 suggested for Nigerian soils [36], implying that there is a possibility of P deficiency in the soils.

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Total nitrogen ranged from 0.0250 to 0.1117 percent. The values were below the recommended critical value of 0.2% [37]. The low nitrogen could be due to the sandy nature of the soils. It was affirmed that soil nitrogen content depends more on inorganic colloids, and higher sand content lowers inorganic colloids in soils [38]. There was variation in the total nitrogen content between the land use types. The lowest value was recorded in FAL; this was one of the reasons for keeping the land fallow in other restore its fertility; it had been used continuously for arable crops for over 28 years and had lost fertility.

The organic carbon values were between 0.5875 and 1.4975 percent. There was a significant difference between the land use types with high variation, as shown by the CV value of 36.640%. The lowest value was recorded on the fallow land, while the highest value was in livestock land. The higher value in the livestock land (LIV) could be a result of the addition of livestock waste to the soil; this implies that livestock waste has the potential of to increase the organic carbon content and overall fertility of the soils in the study area.

Table 1: LSD mean separation and coefficient of variation (CV) of soil properties between the land use types

Land Use	Clay %	Silt	Sand	Texture	Bulk Density g/cm^3	pH	P (mg/kg)	TN (%)	OC (%)	OC$_{(grC/kg\ soil)}$	SC
ARB	6.850ab	6.175b	86.975bc	LS	1.445a	6.4250a	5.205b	0.0425bc	1.0275ab	10.275ab	4.4575ab
FAL	8.225a	6.900a	84.875c	LS	1.453a	4.6000a	11.610ab	0.0250c	0.5875b	5.875b	2.5600b
LIV	4.350bc	6.900a	88.750ab	S	1.423a	5.2750bc	16.735ab	0.11175a	1.4975a	14.975a	6.3975a
NUR	9.100a	6.025a	84.875c	LS	1.455a	4.7500cd	26.060a	0.1050a	1.3625a	13.625a	5.9250a
OM1	3.100c	6.900a	90.000a	S	1.400a	5.4000bc	20.400ab	0.1100a	1.3625a	13.625a	6.7200a
OM2	4.600bc	7.400a	88.750ab	S	1.420a	5,2500bcd	11.500ab	0.0900ab	1.2500a	12.500a	5.3250a
OM3	4.100bc	7.400a	88.500ab	S	1.423a	5.4500bc	4.705b	0.0875ab	1.1475ab	11.475ab	4.8950ab
VEG	3.600c	6.500a	89.750ab	S	1.403a	5.5000b	8.393ab	0.0900ab	1.1625a	11.625ab	4.4575ab
CV (%)	51.759	9.856	3.111		1.822	12.129	107.72	55.489	36.670	36.670	36.402

P= available phosphorus, TN= total nitrogen, OC= organic carbon, SC= soil carbon sequestered

3.2 Soil carbon sequestration

The soil carbon sequestration of the land use types (Figure 1) revealed that OM1 had the highest value of soil carbon stock of 6.72 tons/ha, followed closely by LIV land use with 6.3975 tons/ha. The higher values obtained at the OM1 can be attributed to the long-term non-disturbance of the soil, continuous incorporation of oil palm residues (leaves and flowers), as well as plant cover for over 40 years of the establishment of the plantation. In the LIV use, the supply of organic matter-rich livestock waste could have contributed to the higher soil carbon stock. This implied that the supply of organic materials (plants and animals) contributed to soil carbon sequestration in the study location. Higher soil carbon sequestration in soils treated with organic materials than in conventional soils has been reported [39, 40]. Crop cultivation practices also have an effect on soil carbon sequestration in the study location.

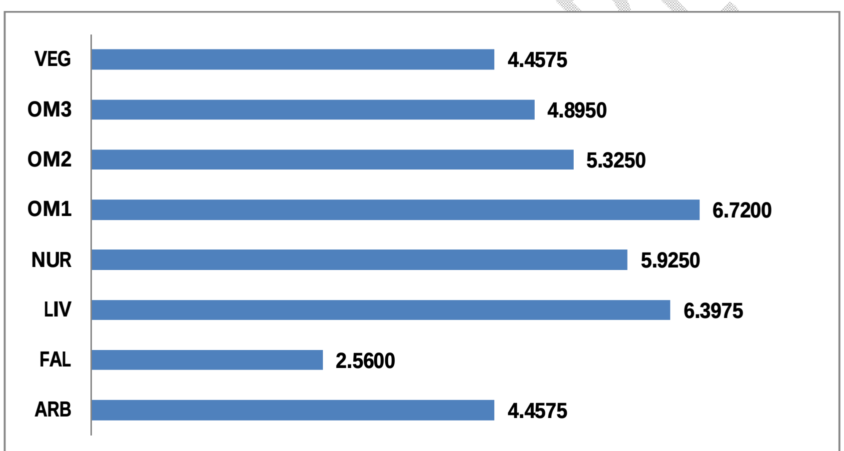

Figure 1: Soil carbon sequestration of the land use types

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The soil carbon sequestration of the land use types (Figure 1) revealed that OM1 had the highest value of soil carbon stock at 6.72 tons per hectare; this is followed closely by LIV land use at 6.3975 tons per hectare. The higher values obtained at the OM1 can be attributed to the long-term non-disturbance of the soil, continuous incorporation of oil palm residues (leaves and flowers), as well as plant cover for over 40 years of the establishment of the plantation. In the LIV use, the supply of organic matter-rich livestock waste could have contributed to the higher soil carbon stock. This implied that the supply of organic materials (plants and animals) contributed to soil carbon sequestration in the study location. Higher soil carbon sequestration in soils treated with organic materials than in conventional soils has been reported [39, 40]. Crop cultivation practices also have an effect on soil carbon sequestration in the study location.

Table 2: Correlation between soil properties and soil carbon sequestration

Soil Properties	Soil Carbon Sequestration
BD (g/cm3	-0.2541*
OC	0.9987*
TN	0.8850*
AP	-0.2041
pH	0.2656
Sand	-0.2419*
Silt	0.0201
Clay	-0.2385*

Lower values were recorded in the FAL (2.56 tons/ha), ARB (4.4575 tons/ha), VEG (4.4575 tons/ha), and OM3 (4.895 tons/ha). These lower values can be attributed to tillage, crop removal, poor post-harvest residue management, and low organic manure and carbon input coupled with the sandy nature of the soil in the location. [41] attributed the decrease in soil carbon sequestration in land converted from grassland or forests to arable land to the decreased carbon input and physical protection of soil organic matter. [4] emphasized soil aggregation, erosion, drainage, aeration, water-holding capacity, bulk density, and permeability as factors influencing soil organic carbon sequestration. All these factors had been reported by [42] to be significantly related to particle size distribution and soil texture. Coarse-textured soils are prone to leaching and loss of organic carbon [43, 44].

3.3 Correlation between soil properties

The correlation matrix for soil properties and soil carbon sequestration is presented in Table 2. Soil carbon sequestration (SC) had a significant negative relationship with bulk density (-0.2541*), sand (-0.2419*), and clay (-0.2385*). This implied that an increase in these properties would lead to a decrease in soil carbon sequestered in the area. A similar result was obtained by [45], and it was attributed to the dilution effect of the low density of organic compounds. There was a significant positive relationship between SC and organic carbon (0.9987*) and total nitrogen (0.8850*). Organic carbon was strongly related to SC, and a high amount of total nitrogen could be reserved in the organic complex of the soils [42]. The enhancement of soil carbon sequestered will lead to numerous ancillary benefits, among which are increased nitrogen retention and availability to plants [46, 47]. The adoption of practices that will lower the bulk density and encourage the addition of organic matter will aid soil carbon sequestration in the study area.

4. Conclusion and Recommendation

It was discovered that the study area's land use types had an impact on the distribution of soil properties studied. Tillage and cultivation activities had an effect on the soil properties and soil carbon sequestration. The less cropped soils and the ones with supplies of organic manure (Oil Palm Plantation 1 and livestock) had the highest soil carbon stock. Soil bulk density was found to be related to soil carbon stocks and influenced its distribution in the land use investigated.

In a bid to promote long-term soil carbon sequestration, the establishment of oil palm plantations in areas suitable for oil palm cultivation is recommended. Specifically in sandy soils to prevent soil chemical property depletion. Practices that will improve the soil bulk density and increase the soil organic matter are also suggested. This will involve no-till or minimal till, the planting of cover crops, the use of organic manure, the introduction of high residue crops and perennial legumes or grass in crop rotation, discouraging the use of machinery when the soil is wet, and the cultivation of crops with different rooting depths in mixed cropping to help break up compacted soil layers.

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